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Technical Report No. 24

SACLANT ASW
RESEARCH CENTER

AN ANALOGUE RECORDING SYSTEM FOR RECORDING PULSE SERIES

by

R. PESARESI and R. FRASSETTO

1 APRIL 1964

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VIALE SAN BARTOLOMEO, 92
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Summary

An analogue recording system for the visual display of pulse series intermittently received from oceanographic sensors is described. It is composed of a mechanically-modified pen recorder and a newly designed electronic driving unit, and it includes arrangements for (a) regulating the speed of the pulse-marking device by means of a stable reference frequency, (b) starting each pulse series on command, and (c) expanding the measuring scale. These requirements could not be found in commercially available recorders, necessitating the development of the one described.

The system can be used either for simultaneous recording, being suitable for use on board ship, or for play-back recording from magnetic tape.

1. INTRODUCTION

During the last few years, several systems have been devised for the synoptic recording of ocean variables in both space and time. The recording system here described (Fig. 1) has been developed to meet the requirements of a particular method of measuring, transcribing and telemetering these data.

Simultaneous measurements of oceanographic variables at different depths can be made efficiently by a vertical array of electronic probes supported by a moored buoy. When continuous measurements are not mandatory, data sampling can be intermittent, the interval between cycles ranging from a few seconds to several hours, as desired. The buoys can thus be left on station for long periods at a time, and their data recorded on magnetic tape.

An effective, inexpensive system of transcribing and telemetering the data from the probes is to express them in terms of brief time intervals between electronic pulses, a series of such intermittent pulses representing a cycle of simultaneous measurements by all the probes on the array. An associated programmer, consisting of a precision timer controlled by a crystal oscillator, commands the starting time of each cycle of measurements and provides a precision time reference for measuring the pulse intervals. This programmer is on shore or aboard ship when simultaneous records are being made, but is carried in the buoy with the tape recorder when data are being stored for later play-back recording.

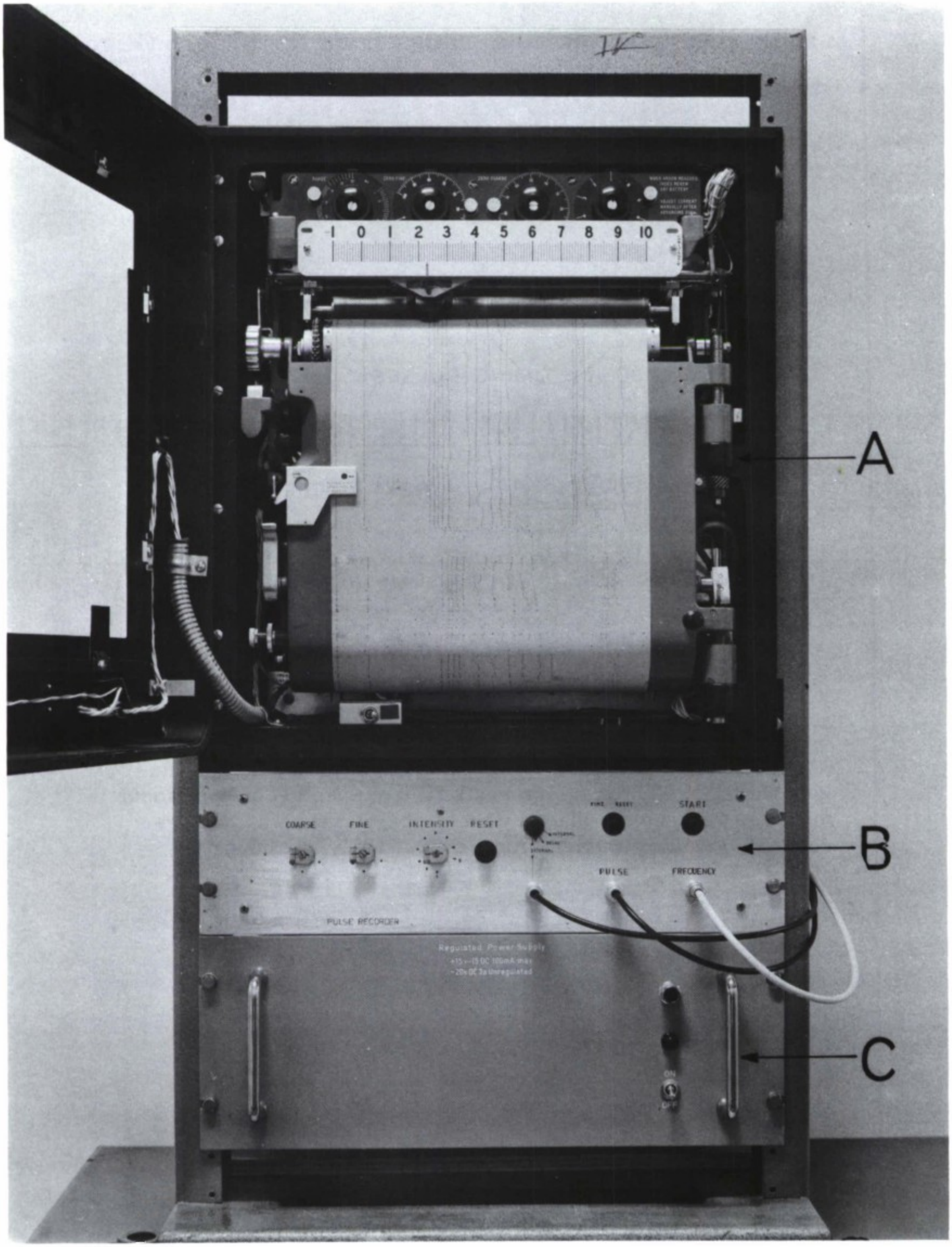

Fig. 1 The complete analogue recorder assembly (approximately 1 m x 50 cm x 40 cm), showing (A) the modified L & N chart recorder, (B) the newly developed driving unit, and (C) the power supply unit.

The analogue recording system to be described therefore receives its input on two channels: Channel 1 carrying the time reference pulses (1000 cps) for the programmer, Channel 2 carrying the data pulses from the probes (Fig. 2).

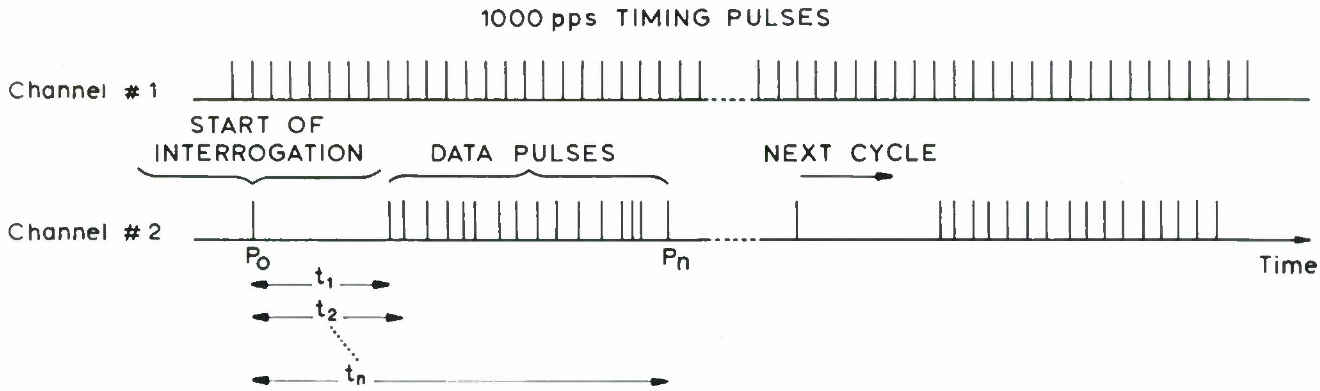

Fig. 2 Schematic representation of the pulses sent out by the oceanographic buoy. The time intervals t_1, t_2, . . . t_n are proportional to the measurements made by the probes 1, 2, . . . n, and are counted against the time reference frequency of Channel 1.

2. REQUIREMENTS

To obtain a clear, accurate record of the pulse series, on command, the following requirements must be fulfilled:

a. The recording system must be capable of registering pulses as short as 5 ms, for which the stylus must mark a clearly-visible, dot-like trace.

b. The width of the recording chart must be large enough to permit good resolution.

c. The start of each sweep of the stylus must be commanded by the start pulse (P_0) arriving from the buoy at the beginning of each measurement cycle.

d. The sweep distance of the stylus must be proportional only to the precision time reference (in Channel 1, Fig. 1), and not to the speed of the magnetic tape recorder's motor, when that is in use.

e. The maximum timing error must be less than 1% of the sweep time, and a visual indication of the occasional errors due to electronic or mechanical instability must be provided.

f. Auxiliary controls should make it possible to expand the scale of any selected section of the pulse series.

3. DESIGN

3.1 Mechanical Design

Requirements (a) and (b), above, concern the recording unit itself. They were met by the modification of a Leeds & Northrop potentiometric chart recorder, already available at the Centre. This recorder uses 10 in. wide paper, thereby satisfying requirement (b). Requirement (a) was satisfied by replacing the ink pen by an electrically insulated stylus and the standard chart by an electro-sensitive one. (Fig. 3).

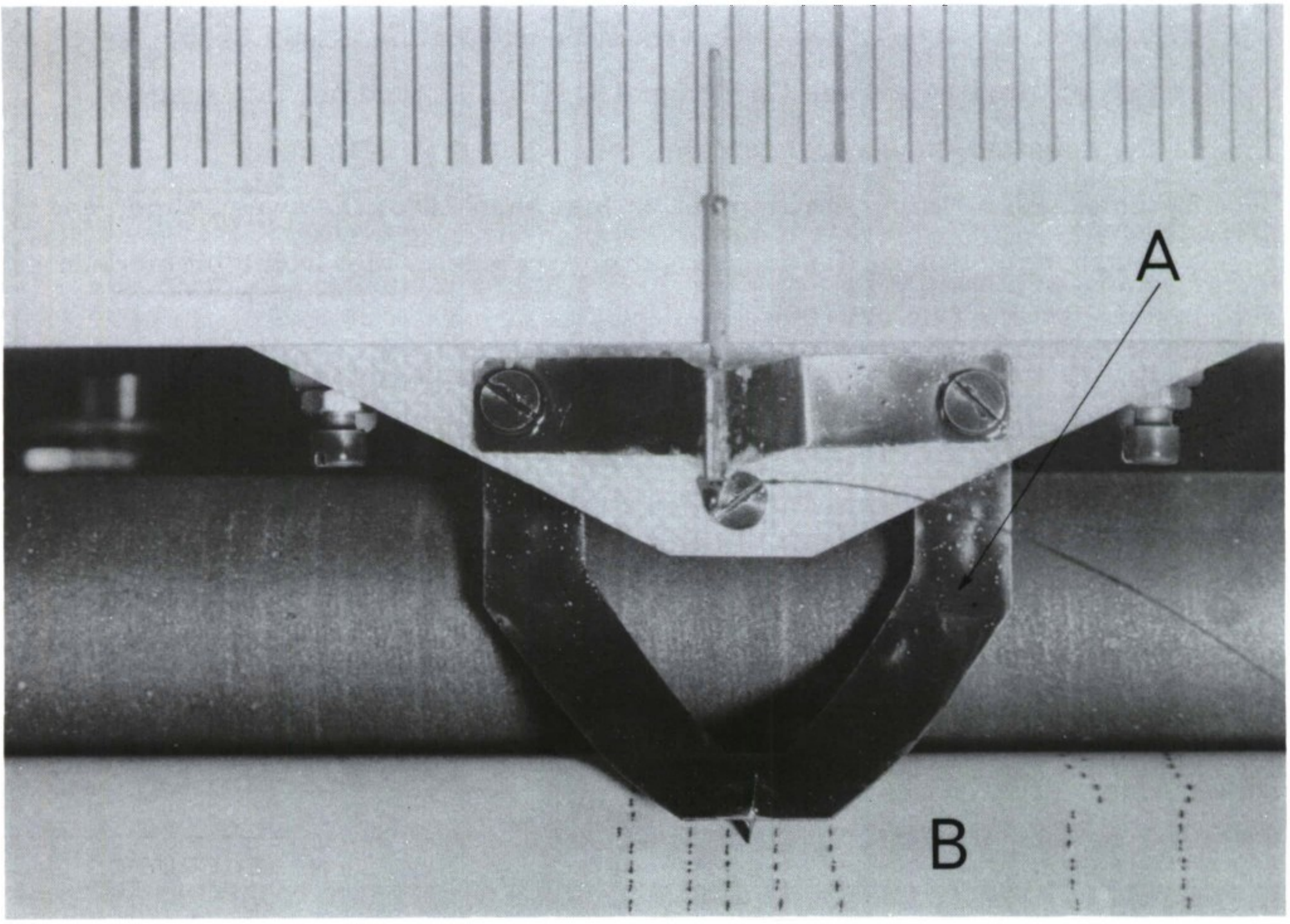

Fig. 3 Detail of modifications to the L & N chart recorder, showing (A) the electric stylus replacing the original pen marker, and (B) the electrosensitive paper replacing the standard L & N chart..

With these modifications, the recorder, coupled to a suitable driving unit, can transcribe the data pulse sequences into a series of discrete dots, thereby forming the required graphs.

3.2 Electronic Design

Requirements (c) and (d) are fundamental; for it was these that could not be satisfied commercially, and necessitated the construction of this recorder system. They have been met by means of the electronic unit (Fig. 4) described in the succeeding pages and analysed in details in the Appendices. Within this unit have been incorporated other circuits to satisfy requirements (e) and (f).

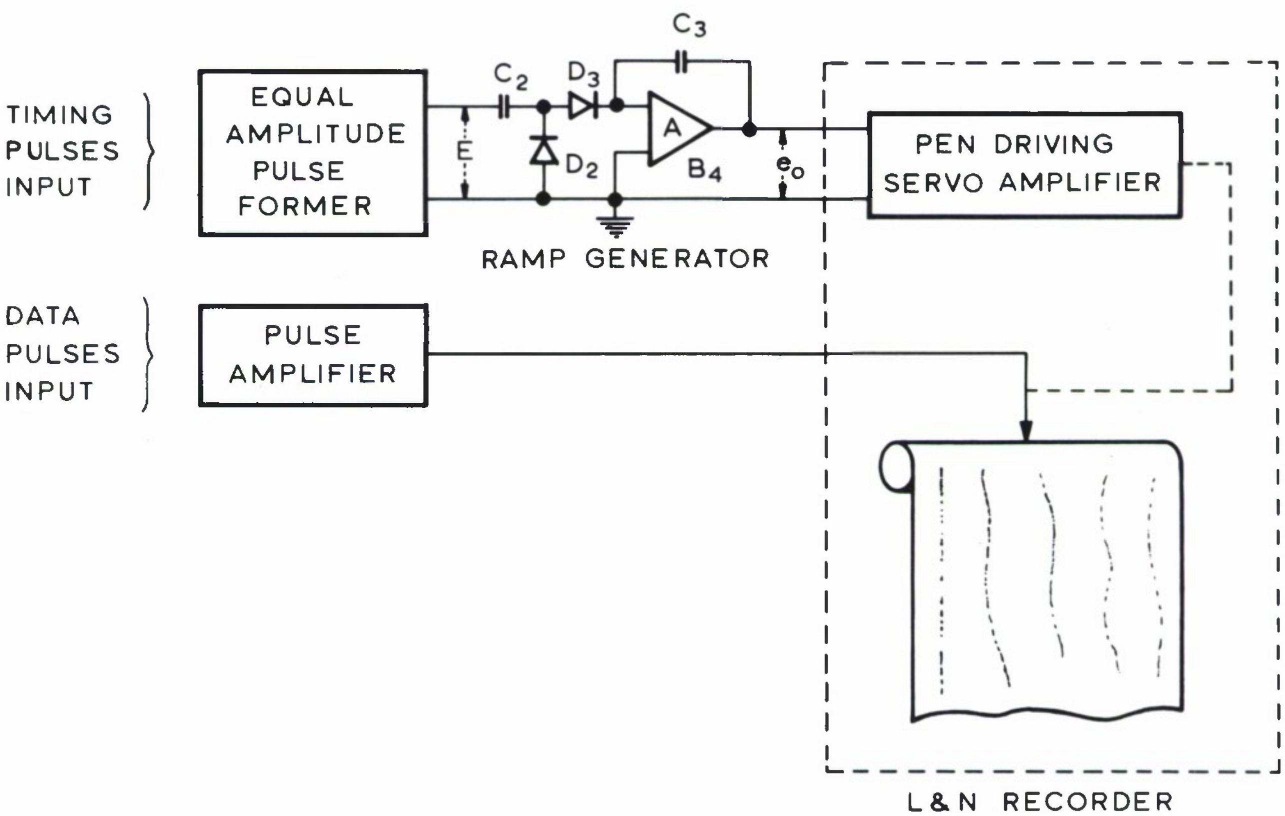

Fig. 4 Block diagram showing the fundamental design of the electronic unit, and, in particular, how a Ramp Generator is used as a Driving Unit.

The working principles can be followed by reference to Appendix C (Fig. 7). Consider the unit in its normal condition, with switch S1 in the "Internal" position. Data pulses are fed into the unit through connector J3, and, after passing the pulse shaper B23 and the "or" gate B24, trigger the one-shot multivibrator B25. The start pulse, P_o, then passes through S1, and reverses flip-flop B5, which in turn causes the amplifier B6 to pperate the reed-relay RL1. The contacts of this relay are normally closed, preventing the sweep driving unit from operating, and leaving the stylus in its left-hand position; when the start pulse opens this relay, the stylus starts a sweep across the paper. Requirement (c) above is thereby satisfied.

The sweep driving unit receives the time reference pulses through connector J1. These are converted into pulses of uniform length in the pulse-shaping circuits B1 and B2, and are brought to constant amplitude by means of the switching circuit B3, the resistor R3, the zener diode D1, the capacitor C2, and the diode D2. The resulting uniform pulses, with an amplitude of 6 v and a duration of 0.3 ms, are fed through diode D3 into the integrator circuit formed by the amplifier B4 and the capacitor C3. Resistors R5, R6, R7, and R8 form a voltage dividing circuit; by varying R6 and R7 the sweep time may be changed by a factor of 50.

In Appendix A, the correlation between the output voltage of the sweep driving unit and its circuit characteristics are demonstrated, the direct dependence of the output voltage $e_o(t)$ on the reference frequency f(t) being expressed in the formula: [Eq. (A.4).]

$$e_o(t) = \frac{C_2}{C_2 + C_3} \cdot E \int_o^t f(t)\ dt$$

This output is connected, through contacts J4-1 and J4-2, to the amplifier and servo-motor driving the recorder stylus, thereby satisfying the requirement (d) that the sweep distance of the stylus be proportional to the time reference.

The starting and subsequent data pulses, passing through B23 and B24, trigger the multivibrator B25, which drives the inverter amplifier B26. This, in turn, drives the power amplifier formed by the transistors Q1 and Q2 and the step-up transformer TR1. The stylus and roller of the recorder are connected, through J4-5 and J4-6, across the secondary winding of TR1; hence, as the stylus is driven across the paper by the sweep driving unit, a mark is made by each of the data pulses. The intensity of these marks is controlled by the potentiometer R32. Diode D20 limits the "ringing" of TR1.

In order to provide a visual indication of the accuracy of the sweep time, as demanded in requirement (e), the start pulse also reverses the flip-flop B22, which in turn opens the "and" gate B7. Time reference pulses are thereby permitted to reach the frequency dividing flip-flops, B8 to B20, of the Time Reference Unit. When the counting cycle is finished, and B20 is reversed, the output signal passes through the differentiating network, C5, R30, D19, to the "or" gate B24. Operating B25 and B26, it causes a mark to be made on the paper; the straightness of the line formed by these marks provides a verification of the stability of the sweep time.

By means of the inverter amplifier B21, and a choice of loops in the feed-back circuit, the counting cycle may be set for any desired time up to 8 sec.

At the end of its sweep, the stylus operates a microswitch that, through connectors J4-3 and J4-4, resets all the flip-flops. A push button switch, S2, is provided for manual resetting.

The final requirement (f) was that it should be possible to expand the scale of any selected section of the pulse series. At the moment, this requirement has been satisfied partially, by making it possible to delay the stylus sweep until any desired time after the arrival of the initial pulse. With switch S1 in the

"Delayed" position, the start pulse no longer passes directly from B25 to trigger the Sweep Driving Unit, but is delayed by passing through the Time Reference and Delay Unit. By feeding a suitable number of the flip-flop outputs to the Delay Gate, any delay of up to 8 sec may be achieved. With switch S1 in the "External" position, the Sweep Driving Unit can be triggered by an external signal arriving through Connector J2, instead of by the start pulse. A manual control system is being developed to satisfy requirement (f) completely.

Figure 5 shows a typical example of a visual display of pulse series representing temperature data, as obtained at sea. In this case, a cycle of measurements from one pressure gauge and 20 thermistor probes was made every 3 min, each cycle lasting 6 sec.

The abscissa shows the time (about 7 hr of recording) and the ordinate shows the pulse series. The latter are marked from top to bottom during each sweep of the electric stylus, arriving in the following order: P_o, the start pulse; D, the return pulse from the pressure gauge; and P_1 to P_{20}, the return pulses from the 20 thermistor probes. Below these are two lines of marks made automatically by the Time Reference Unit: T being the visual verification of sweeping time and S_2 being the time scale : $\frac{1}{2}$ hr on and $\frac{1}{2}$ hr off. A vertical time scale, S_1, is also introduced automatically, each line of dots being separated from the next by $\frac{1}{4}$ sec. The first $\frac{1}{4}$ sec of this scale occupies a shorter space than the others, because the speed of the stylus increases gradually before reaching the steady state; this fact does not affect the use of this scale for quantitative measurements, for which purpose it has been introduced.

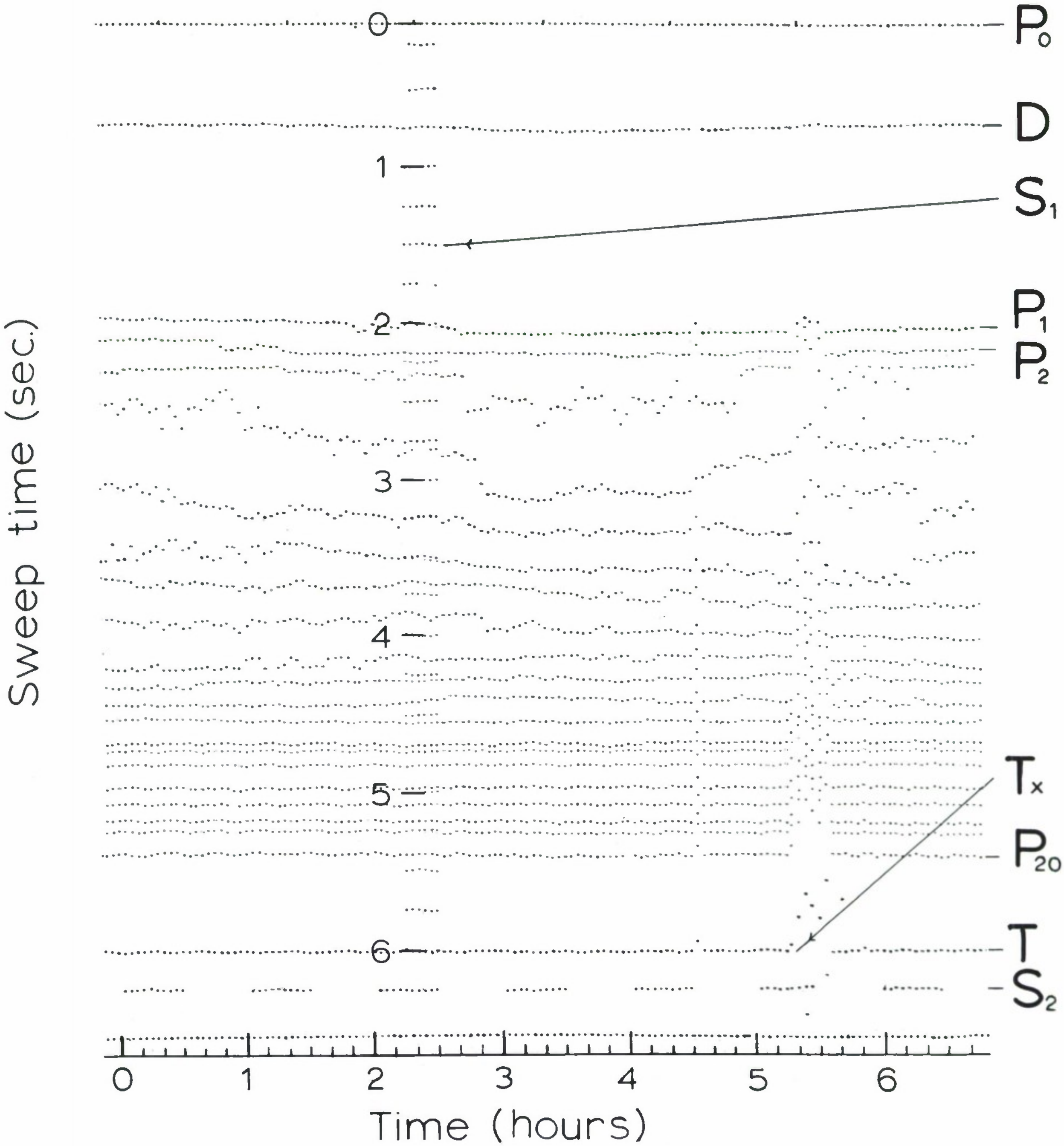

Fig. 5 An example of the visual display of data pulses. The chart shows a 7 hr record of measurements (P_1 - P_{20}) from an array of twenty thermistor probes, there being a 3 min. interval between each measurement cycle. Near the right-hand side of the chart, errors due to the recorder are identified by breaks (T_x) in the sweeping time verification line (T).

3.3 Linearity

The detailed analysis of the circuit given in the Appendices emphasises that, once the capacitors C_2 and C_3 are chosen, the linearity of the system depends essentially on the gain of the sweep driving unit amplifier. This is expressed in Eq. (B.6)

$$d = \frac{k+1}{2} \cdot \frac{1}{A} \cdot \frac{C_2}{C_2 + C_3}$$

where d is the fractional deviation from linearity, C_2 and C_3 are the values of the capacitors in the driving unit, A is the amplifier gain, and

$$k + 1 \approx f \cdot t$$

where f is the reference frequency and t the time in seconds after the sweep.

In the circuit described, the ratio $\frac{C_2}{C_2 + C_3}$ has the value of 0.22×10^{-3}, f is 10^3 pps, t is of the order of 10 sec, and A has a nominal value of 3×10^4. The deviation from linearity is therefore approximately $\pm$ 0.004%, well within the accuracy rating ($\pm$ 0.3% of the span) of the L & N recorder.

3.4 Stability

The stability of the sweep driving unit is high because it depends on that of the amplitude (E) of the pulses, this, in turn, being controlled by a zener diode with a temperature coefficient of 0.01%/$^{\circ}$C. Stability of the L & N recorder is approximately 0.5% of span. This latter, therefore, is the measure of the whole system's stability.

4. CONCLUSIONS

The recording system described has been used successfully for the analogue display of isobathic temperatures measured by a vertical array of twenty thermometers. It is equally suitable for recording several other kinds of isobathic variables, whether these data are telemetered simultaneously from the buoy by radio link or are played back from a self-recording system within the buoy.

The L & N recorder, which was incorporated because of its immediate availability, is too slow for recording long series of stored data, and the present prototype system is now in the process of being modified by the incorporation of a faster chart-recorder.

The accuracy of measurement on the full scale is limited to $\pm$ 0.1°C in the case of temperatures, although greater accuracy can be obtained by expanding the scale. However, this is not the main purpose of the system, which is to provide a visual, preliminary and, if needed, in situ record of the variables under study.

5. ACKNOWLEDGEMENTS

The authors are particularly grateful to Mr. Arne Johansen for reviewing the chapters concerning the electronic circuit, to Mr. V. Manzotti and Mr. A. Chiarabini for the mechanical modifications of the L & N recorder, and to Mr. R. Della Maggiora for building and operating the electronic unit.

APPENDIX A

RAMP GENERATOR CHARACTERISTICS

The design of the ramp generator is shown schematically in Fig. 4, and consists of the diodes D2 and D3, the capacitor C2, and the integrator formed by the amplifier B4 and the capacitor C3.

As a first approximation, suppose both the amplifier gain A and its input impedance Z_i to be infinite. Then both the amplifier's input voltage e_i (where $e_i = e_o/A$), and its input current i_i (where $i_i = e_i/Z_i$) can be considered approximately equal to zero.

The input of the circuit is supplied with pulses of constant amplitude E, derived from the external timer. Each pulse, as it arrives in the circuit, charges condenser C_2 through diode D_2, and discharges it through diode D_3 into condenser C_3, thereby raising the output voltage by a small step Δe_o, where

$$\Delta e_o = \frac{C_2}{C_2 + C_3} \cdot E \qquad (A.1)$$

(if e_i is assumed to be zero). This causes a small movement of the stylus across the chart.

Therefore, the output voltage e_o of the ramp generator is not continuous, but is made up of a distinct number n(t) of such steps, one for each cycle of the reference frequency f(t) arriving within time t. This may be expressed as

$$e_o(t) = \sum_{i=1}^{n(t)} \Delta e_{oi}$$

$$= \frac{C_2}{C_2 + C_3} \cdot E \cdot n(t) \qquad (A.2)$$

However, by definition

$$n(t) = \int_{o}^{t} f(t)\ dt \tag{A. 3}$$

and therefore

$$e_o(t) = \frac{C_2}{C_2 + C_3} \cdot E \int_{o}^{t} f(t)\ dt \tag{A. 4}$$

and

$$\frac{de_o(t)}{dt} = \frac{C_2}{C_2 + C_3} \cdot E \cdot f(t) \tag{A. 5}$$

Thus, the average slope of the output voltage is proportional to, and, hence, is controlled by, the input frequency.

In the particular case where the reference frequency F is constant, it is seen that the output increases linearly with time, as in the equation

$$e_o(t) = \frac{C_2}{C_2 + C_3} \cdot E \cdot F \cdot t \tag{A. 6}$$

The number of cycles of the reference frequency required to carry the stylus across the chart depends on the integration constant, and on the value of the voltage-dividing network following the amplifier. As the input voltage e_r of the recorder is given by

$$e_r(t) = \frac{R_8}{R_5 + R_8} \cdot e_o(t)$$

then, by substituting Eq. (A. 2), the number of pulses required for full-scale deflection of the stylus is seen to be

$$n(\text{full-scale}) = \frac{C_2 + C_3}{C_2} \cdot \frac{1}{E} \cdot \frac{R_5 + R_8}{R_8} \cdot e_r\,(\text{full-scale}) \qquad \text{(A. 7)}$$

The number of pulses required for a full-scale deflection is modified easily by changing the ratio $(R_5 + R_8)/R_8$, as it is preferred to keep $(C_2/C_3)/C_3$ and $1/E$ constant for stability reasons.

As the use of a ramp generator gives a step-like character to the recorder input voltages, it might be expected that this would be reflected in the movement of the stylus. This does not occur, however, because inertia in the stylus system automatically integrates the steps and gives a smooth, continuous action.

APPENDIX B

LINEARITY

In Appendix A it was assumed that the amplifier gain A was infinite, and that the input voltage e_i was therefore, in effect, zero. In fact , the amplifier gain has some finite value, depending on the amplifier used; the effect of the input voltage on the discharging of C_2 into C_3 must therefore be taken into account. (In the analysis, the sign of this gain - which is negative - is ignored).

Therefore, consider the situation at k pulses after the start of integration. The input voltage at the amplifier is then

$$e_{i,\,k} = \frac{e_{o,\,k}}{A}$$

and the available charge in C_2 is

$$Q = C_2 \cdot E$$

When the $(k+1)^{th}$ pulse causes C_2 to discharge into C_3, the actual charge transferred, Q_k, is only

$$Q_k = C_2 \cdot \left(E - e_{i,\,k}\right)$$

because the input voltage e_i is not actually zero and has the same sign as E. Thus the step in output voltage $e_{o,\,k}$ is represented by

$$e_{o,\,k} - e_{o,\,k-1} = \frac{C_2}{C_2 + C_3} \left(E - \frac{e_{o,\,k}}{A}\right) \qquad \text{(B.1)}$$

$$= \frac{1}{A} \cdot \frac{C_2}{C_2 + C_3} \cdot \left(A \cdot E - e_{o,\,k}\right)$$

If both positive and negative values of $A \cdot E$ are introduced into the left-hand side of Eq. (B. 1), one obtains

$$-\left(A \cdot E - e_{o,k}\right) + \left(A \cdot E - e_{o,k-1}\right)$$

$$= \frac{1}{A} \cdot \frac{C_2}{C_2 + C_3} \cdot \left(A \cdot E - e_{o,k}\right) \qquad (B. 2)$$

If the variables $\mathcal{E}_k$ and γ are introduced, such that

$$\mathcal{E}_k \equiv A \cdot E - e_{o,k}$$

and

$$\gamma \equiv \frac{1}{A} \cdot \frac{C_2}{C_2 + C_3}$$

then Eq. (B. 2) becomes

$$\mathcal{E}_k - \mathcal{E}_{k-1} = \gamma \mathcal{E}_k$$

or

$$\mathcal{E}_k = \frac{1}{1+\gamma} \cdot \mathcal{E}_{k-1} \qquad (B. 3)$$

Successive multiplications of the right-hand side of Eq. (B. 3) give

$$\mathcal{E}_k = \frac{1}{(1+\gamma)^k} \cdot \mathcal{E}_o \qquad (B. 4)$$

The initial condition determining $\mathcal{E}_o$ was that the voltage of condenser C_3 was zero at the beginning of integration ($k = 0$). Then

$$e_{o,0} = 0$$

and hence

$$\mathcal{E}_o = A \cdot E$$

Thus Eq. (B. 4) becomes

$$\mathcal{E}_k = A \cdot E \cdot \frac{1}{(1+\gamma)^k}$$

and thereby it is seen that

$$e_{o,k} = A \cdot E \left[1 - \frac{1}{\left(1 + \frac{1}{A} \cdot \frac{C_2}{C_2 + C_3}\right)^k} \right] \qquad \text{(B. 5)}$$

In the cases where the term

$$\gamma = \frac{1}{A} \cdot \frac{C_2}{C_2 + C_3}$$

has the values much less than unity, Eq. (B. 5) reduces to

$$e_{o,k} = \frac{C_2}{C_2 + C_3} \cdot E \cdot K$$

which is Eq. (A. 2), as k is a value of n(t).

The linearity δ is expressed by dividing the difference between the linear [Eq. (A. 2)] and actual [Eq. (B. 5)] values of the output voltage by the linear value

$$\delta = \frac{\frac{C_2}{C_2 + C_3} \cdot E \cdot k - A \cdot E \left[1 - \frac{1}{\left(1 + \frac{1}{A} \cdot \frac{C_2}{C_2 + C_3}\right)^k} \right]}{\frac{C_2}{C_2 + C_3} \cdot E \cdot k}$$

$$= 1 - \frac{1}{\gamma k} + \frac{1}{\gamma k} \cdot (1 + \gamma)^{-k}$$

$$= \frac{k+1}{2} \gamma \left(1 - \frac{k+2}{3} \gamma^2 + \ldots\right)$$

Thus the linearity depends essentially on the term

$$d = \frac{k+1}{2} \gamma$$

$$= \frac{k+1}{2} \cdot \frac{1}{A} \cdot \frac{C_2}{C_2 + C_3} \qquad \text{(B. 6)}$$

and, thereby, essentially on the amplifier gain.

APPENDIX C

The following tables (Tables 1 and 2) give the characteristics of all the electronic components used. Table 1, which describes the pre-built circuit blocks, is supplemented by Fig. 6, on which the internal circuits of these blocks are shown. The locations of the components in the circuit are shown in Fig. 7.

TABLE 1

PRE-BUILT CIRCUIT BLOCKS

Number on Fig. 7	Designation	Manufacturer	Description	Number on Fig. 6
B 1	PSI	Philips	Pulse-shaper	6d
2	OSI	"	One-shot multivibrator	6e
3 (x 6)	2. IA1	"	Inverter amplifier	6c
4	P2	Philbrick	Operational amplifier	-
5	FF1	Philips	Flip-flop	6a
6 (x 3)	2. IA1	"	Inverter amplifier	6c
7 (x24)	2. 2N1	"	Gate	6b
8-20	FF1	"	Flip-flop	6a
21 (x26)	2. IA1	"	Inverter amplifier	6c
22	FF1	"	Flip-flop	6a
23	PSI	"	Pulse-shaper	6d
24 (x 7)	2. 2N1	"	Gate	6b
25	OS1	"	One-shot multivibrator	6e
26 (x21)	2. IA1	"	Inverter amplifier	6c

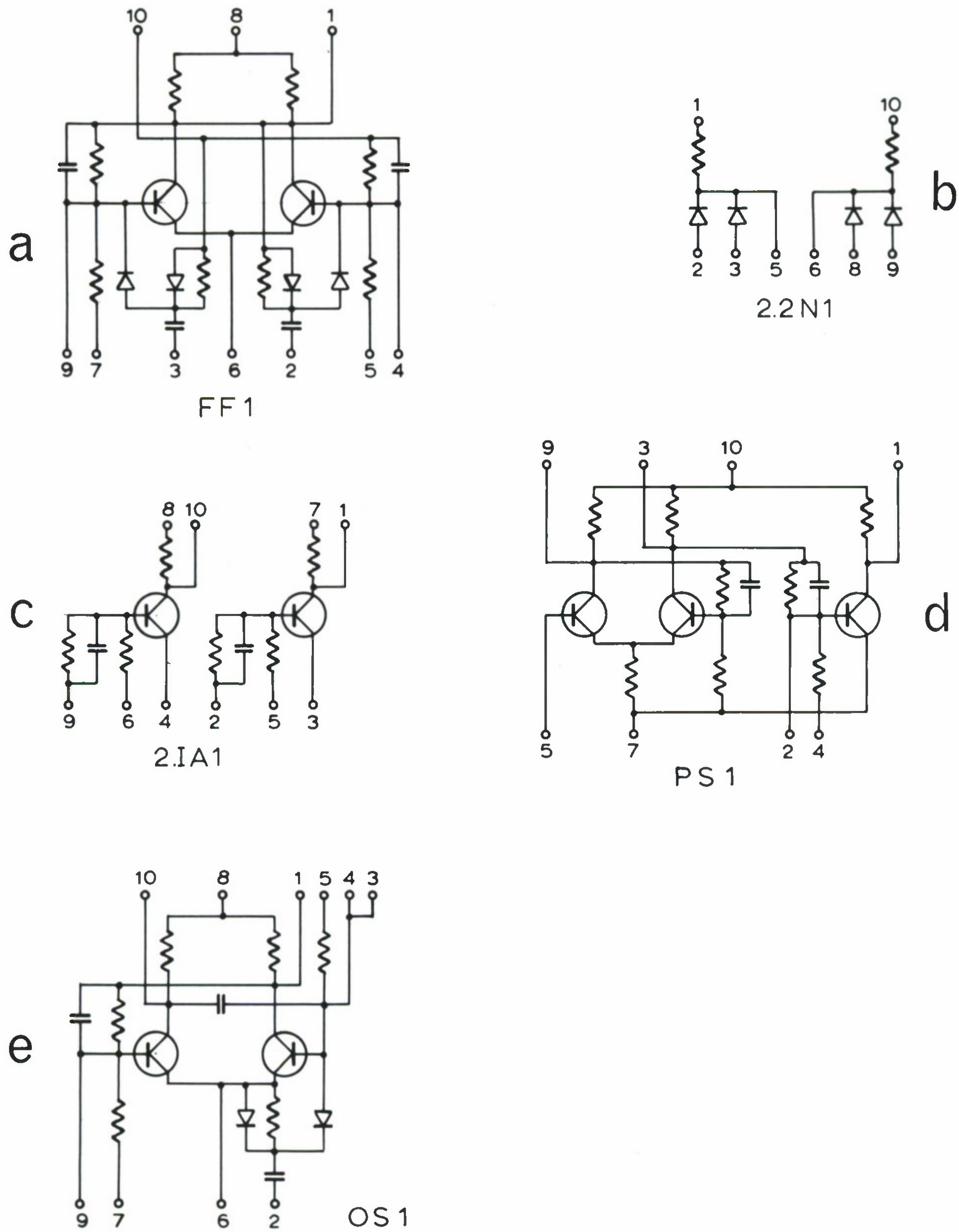

Fig. 6 Internal circuits of the pre-built circuit blocks. Descriptions are given in Table 1.

TABLE 2

INDIVIDUAL ELECTRONIC COMPONENTS

Type	Number on Fig. 7	Value	Designation	Manufacturer
Capacitor	C 1	33 Kpf	"Mylar" dielectric	
	2	220 Kpf	Mica dielectric	
	3	1 μf	"Mylar" dielectric	
	4	1.5 μf	Ceramic dielectric	
	5	1.5 μf	Ceramic dielectric	
Resistor	R 1	1.5 kΩ (10%)		
	2	10 kΩ (10%)		
	3	3.3 kΩ (2%)		
	4	10 Ω (10%)		
	5	22 kΩ (2%)		
	6	1 kΩ (lin.)		
	7	100 Ω (lin.)		
	8	22 Ω (2%)		
	9	2.7 kΩ (10%)		
	10	10 kΩ (10%)		
	11-24	2.7 kΩ (10%)		
	25	10 kΩ (10%)		
	26	22 kΩ (10%)		
	27	10 kΩ (10%)		
	28	1.5 kΩ (10%)		
	29	10 kΩ (10%)		
	30	10 kΩ (10%)		
	31	1 kΩ (10%)		
	32	30 Ω (lin.)		
	33	10 kΩ (10%)		
Transistor	Q 1		OC80	Philips
	2		ASZ 16	Philips
Diode	D 1-19		OA 200	Philips
	D 20		OA 210	Philips
Transformer	TR 1		LS 56	U.T.C.
Connectors	J 1, 2 & 3		BNC	
	J 4		AN	
Relay	RL 1			Hamlin
Switch	S 1			Centralab
	S 2			Centralab

(Reverse Blank)

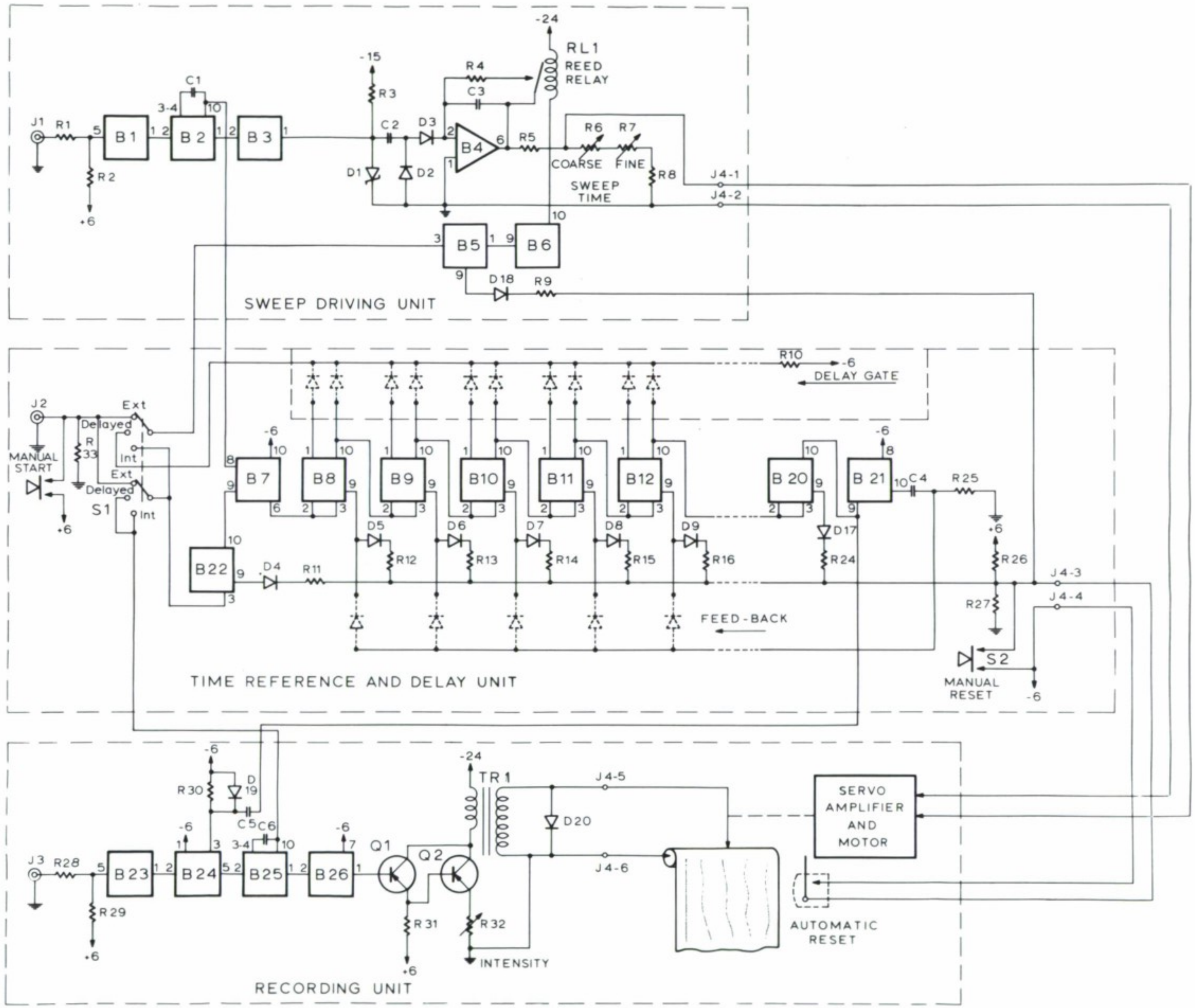

Fig. 7 Circuit diagram of the complete recorder system. The electronic components are listed in Tables 1 & 2.

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